Spacecraft Modularity for Serviceable Satellites

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Spacecraft modularity has been a topic of interest at NASA since the 1970s, when the Multi-Mission Modular Spacecraft (MMS) was developed at the Goddard Space Flight Center. Since then, modular concepts have been employed for a variety of spacecraft and, as in the case of the Hubble Space Telescope (HST) and the International Space Station (ISS), have been critical to the success of on-orbit servicing. Modularity is even more important for future robotic servicing. Robotic satellite servicing technologies under development by NASA can extend mission life and reduce lifecycle cost and risk. These are optimized when the target spacecraft is designed for servicing, including advanced modularity. This paper will explore how spacecraft design, as demonstrated by the Reconfigurable Operational spacecraft for Science and Exploration (ROSE) spacecraft architecture, and servicing technologies can be developed in parallel to fully take advantage of the promise of both.

Spacecraft modularity has many aspects. Perhaps most important is the use of standard interfaces. Standard interfaces provide flexibility, adaptability, ease of manufacture and procurement, simpler integration and test (I&T), and enhanced lifetime via serviceable components and science instruments. Success has been demonstrated by the MMS busses, HST and ISS. In the case of Solar Maximum, the first MMS spacecraft, modularity (and the associated set of standard interfaces) and serviceability enabled the restart of a mission doomed by upper-stage booster failure. For HST, servicing saved the mission and then led to an unprecedented set of mission extensions and

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continued scientific productivity over 25 years via installation of replacement components and new science instruments.

Various technologies are required of both the servicing spacecraft and the target spacecraft. Rendezvous, proximity operations, capture, and servicing are all made easier or more difficult depending on the components and configuration of the two spacecraft. The historical trend has progressed from human-centric servicing via the space shuttle to the current hybrid of robotic/human servicing aboard ISS, to future all-robotic servicing (the Restore-L NASA notional robotic servicer, Wide-Field Infrared Survey Telescope (WFIRST). Key technological features of varying complexity enable and simplify on-orbit servicing; from the trivial (e.g. substituting Velcro for tape to close out MLI blankets), to medium-complex (redesign of a fill and drain valve for robotic-friendly servicing), to challenging (additional overdrive capability to deployables via robotic hex drive).

The ROSE spacecraft architecture is the next step in the progression of robotic-friendly, serviceable, modular spacecraft. Carrying up to four replaceable instruments and six functionally-specific bus modules around a common core, ROSE has a very capable and robust architecture for future science missions (See Figure 1). The robot friendly design allows on-orbit replaceable instruments and bus modules for additional capability or repair of failed units. Refueling ROSE will enable a longer mission lifetime via additional orbit maintenance propellant as well as flexibility to change orbit entirely if desired.

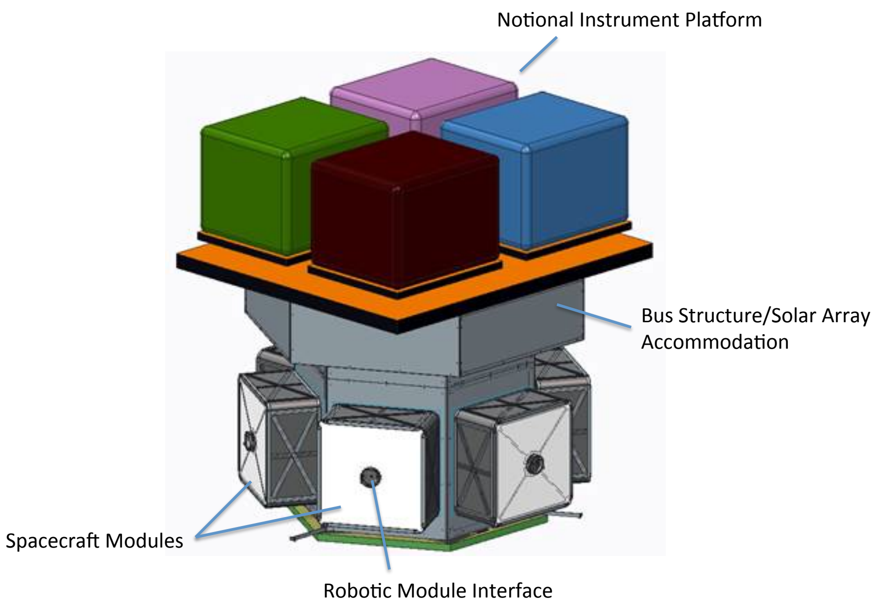

Figure 1: Model of ROSE spacecraft concept

Even independent of servicing, there are significant benefits of modularity for ROSE. In the ROSE architecture, the bus modules interface to the spacecraft electrically through the Module Interface Unit (MIU) and mechanically through robotically compatible advanced latches. Each MIU provides a standard electrical interface to the rest of the spacecraft and a flexible set of interfaces for components inside the module. So components can be changed and upgraded over time with minimal impact to the overall spacecraft design. This lowers cost through increased component competition, and future-proofs the spacecraft to take advantage of component-level technological advances as they occur.

The modularity present in ROSE also provides additional cost and risk reductions. The standard module interfaces allow for common ground support equipment (GSE)and test procedures. Furthermore, integration of modules onto the spacecraft bus will be highly simplified compared to a more traditional design.

The benefits of modularity for on-orbit servicing are even more apparent. The mechanical latch design for ROSE is being developed with robotic servicing as a central objective. As shown in Figure 2 robotic module removal and replacement has been demonstrated on a full size ROSE spacecraft mockup at the Satellite Servicing Center at NASA's Goddard Space Flight Center in Greenbelt, Md. The techniques and approaches already developed will be directly applicable to on-orbit operations. These include not only mechanical latching, but also accurate positioning under realistic operational conditions and actuation of electrical connectors. Similar approaches will be used for removal and replacement of instruments. Finally, these technologies will be extendable to future missions as well, including, for example, WFIRST.

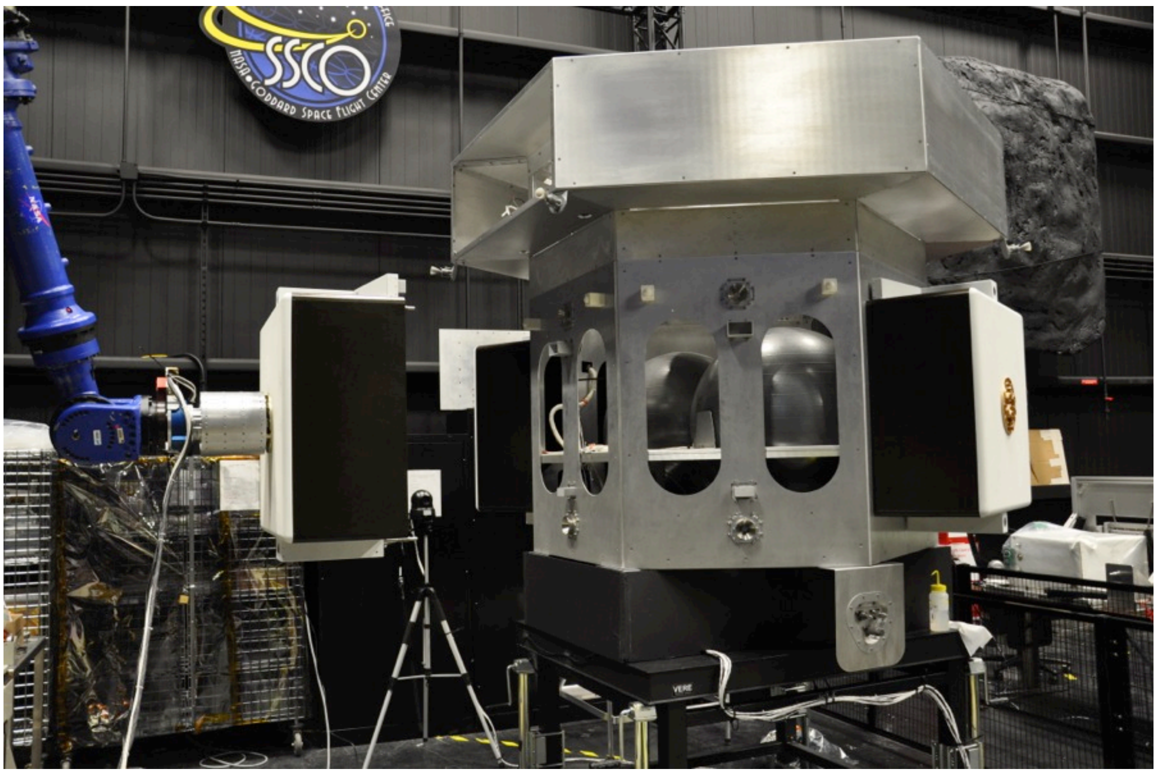

Figure 2: Laboratory demonstration of ROSE module robotic replacement

While the ROSE concept illustrates the promise of servicing for a spacecraft designed with that as a primary objective, servicing has promise even for less "friendly" clients. Through its ground and ISS technology development campaign, NASA's Satellite Servicing Capabilities Office has demonstrated the feasibility of robotic in-orbit satellite servicing for legacy satellites not designed to be serviced on-orbit, namely relocation and refueling. The possibilities are far greater with complementary forethought and action on the part of potential "future clients" and those who support them: international institutions and agencies, satellite manufacturers, fleet owners and operators, insurance providers, and fledgling service providers. With a robust and sustained number of new spacecraft arriving in orbit annually, the question is begged, what low impact servicing aids on these new spacecraft will ensure that the entire community can collectively reap the full benefits that the emerging servicing industry offers.

Building from our body of experience in human and robotic servicing, the authors will put forth a set of cooperative servicing aids for consideration by the community. Every servicing mission that we have investigated and executed – beginning with the Solar Max repair, continuing through the Hubble Space Telescope servicing missions, and now developing a concept for a robotic servicer – has brought us to a recognition of specific aids that would have made the task cooperative, and therefore easier. That thought process is reflected within the list.

The advantages of modularity and design for servicing can far outweigh the costs. The ROSE spacecraft architecture is being developed to work seamlessly with future robotic servicing capabilities, such as the notional Restore-L servicer, and allow these advantages to be fully realized. With the new mandate (51 U.S. Code § 70508) for observatory class missions to be serviceable, future missions such as WFIRST require these features. ROSE will serve as a pathfinder, exploring best practices and providing lessons for the new serviceable space architectures of the future.